recommended to the general reader also, because the style is simple and the ideas are clearly and logically developed and followed. With the growing interest in metallography as a method of testing and of research it will undoubtedly prove very popular.

W. CAMPBELL

SPECIAL ARTICLES

THE TEMPORAL FOSSÆ OF VERTEBRATES IN RELATION TO THE JAW MUSCLES

ABOUT two years ago one of us (Gregory) discovered that the superior and lateral temporal fenestræ of all two-arched reptiles and the single fenestra of all one-arched reptiles appear to be related to the jaw muscles in such a way that they either give exit to them upon the top of the skull or afford room for them at the sides. It was afterward learned that Dollo[1] had reached the same conclusion in 1884, but his important results have been practically ignored in the subsequent literature of the temporal fenestræ, which have been considered too largely from a purely taxonomic viewpoint and too little with reference to their adaptational significance.[2]

More in detail, the steps leading to the present note were chiefly as follows:

It was observed that the temporal fossæ of *Cynognathus* and other Theriodonts present close resemblances to those of primitive mammals and it thus seemed highly probable that in these reptiles the sagittal and occipital crests, together with the zygomatic and postorbital borders, bounded the homologue of the mammalian temporalis muscle. Comparison with the snapping turtle *Chelydra* suggested that in this case also the backwardly prolonged sagittal crest served for the attachment of the temporalis; and this gave added significance to the immense temporal fossæ and massive mandible of *Chelone*. The partial excavation of the dorsal roof over the temporal muscles in *Chelydra* appeared to give this muscle more room for action, and the almost complete removal of the temporal roof in *Trionyx* seemed to give further evidence in the same direction.

In *Sphenodon* it was seen that the borders of the superior temporal fenestræ apparently served for muscle attachment, and dissection of a specimen of this animal showed that this inference was correct, and that the lateral temporal fenestræ gave room for the expansion and contraction of the voluminous muscle mass. It was further recalled that in the most primitive Tetrapoda (stegocephalians and cotylosaurs) as well as in primitive Osteichthyes (*Polypterus*, Devonian Rhipidistia, Dipnoi, etc.) the temporal region is completely roofed over, while modernized forms such as Urodeles, Anura, lizards and snakes have the outer temporal roof reduced to slender bars or even entirely absent. The presence of a sagittal crest in *Amphiuma* indicated that in the modernized Urodeles the temporal muscles had extended on to the top of the skull. From such observations the following inferences were drawn:

1. That in primitive vertebrates the chief temporal muscle-mass (adductor mandibulæ of sharks) was originally covered by the dermal temporal skull-roof.

2. That in modernized Amphibia and Reptilia, as well as in birds and mammals, one or more slips of the primitive adductor mass had secured additional room for expansion by perforating the temporal roof either at the top or at the sides or in both regions at once; much as in hystricomorph rodents a slip of the masseter has invaded the region of the infraorbital foramen, so that it now extends through a widely open arcade and finds room for expansion on the side of the face.

3. A comparative study of the skull of *Tyrannosaurus*,[3] in connection with the above-mentioned observations and conclusions, led to the suspicion that the antorbital fenestræ of

[1] "Les Muscles éleveurs de la Mandibule et leur Influence sur la Forme du Crâne: Cinquième Note sur les Dinosauriens de Bernissart," *Bull. Mus. Roy. Hist. Nat. Belg.*, Tome III., 1884, pp. 136–146.

[2] A partial exception to this statement is afforded by Professor Lull's well-studied reconstruction of the cranial musculature of *Triceratops* (*Amer. Jour. Sci.*, Vol. XXV., 1908, pp. 387–99).

[3] Partly embodied in Professor Osborn's memoir on *Tyrannosaurus*, *Mem. Amer. Mus. Nat. Hist.*, N. S., 1912, Vol. I., Pt. I.

dinosaurs, phytosaurs, pterosaurs, etc., were also functionally connected with the muscles of mastication; but it was realized that proof of this view required a wider study of the jaw muscles of living reptiles. It was afterward found that Dollo (1884) had suggested that the antorbital fenestræ of extinct reptiles were filled by the pterygoid muscles.

4. With regard to the supposed relations of the mammals with the Theriodont reptiles, it was thought that some light on the origin of the mammalian alisphenoid and pterygoid and on the probable steps in the transformation of the reptilian into the mammalian condition could be obtained by a study of the muscles of the pterygoid region in existing reptiles and mammals.

5. The supposed transformation of the reptilian quadrate, articular and angular, into the mammalian incus, malleus and tympanic, respectively, as held especially by Gaupp,[4] Gregory,[5] Broom[6] and Watson,[7] might, it was thought, be further elucidated by a careful reconstruction of the jaw muscles of *Cynognathus* and by a study of the muscles of the middle ear in mammals (m. stapedius, m. tensor tympani).

6. In directing the studies of graduate students upon the structural and phylogenetic history of the skull in vertebrates it was found advantageous to emphasize the functional meaning and importance of the chief openings in the skull, and to consider the osseous elements in the temporal and pterygoid regions as if they were mere remnants, or tracts of bone, resulting from the reduction of an originally continuous dermal covering, through the moulding influences of the jaw muscles.

7. In comparing the skull patterns of the oldest Osteichthyan fishes (Dipnoi, Rhipidistia, etc.) sutures came to be regarded as loci of movement or progressive overgrowth, conditioned in part by muscular action, while centers of ossification were considered as loci of relative stability.

At this point the junior author of the present note undertook to make a broad and at the same time sufficiently detailed study of the jaw muscles of vertebrates, partly with the view of testing and extending the foregoing observations and conclusions.

It was soon found that while many anatomists had made intensive studies of the innervation of the muscles of mastication in certain types very few had attempted to follow them throughout the vertebrates and no one had given an adequate series of figures. It is indeed a surprising fact that comparative myology is so briefly treated in the standard text-books. The work has been carried on in the laboratory of vertebrate evolution in the American Museum of Natural History. A series of 26 existing types of vertebrates has been studied and figured as follows: Elasmobranchii 1, Chondrostei 2, Holostei 1, Teleostei 3, Crossopterygii 1, Dipnoi 1, Urodela 3, Anura 1, Chelonia 1, Rhynchocephalia 1, Lacertilia 2, Crocodilia 1, Aves 1, Mammalia 7. In each case special attention has been paid to the innervation of the muscles as a guide to homologies. By means of these data, and of the principles that became apparent as the work proceeded, reconstructions of the jaw musculature were attempted in the following series of extinct forms: *Dinichthys* (Arthrodira), *Eryops* (Temnospondyli), *Labidosaurus* (Cotylosauria), *Cynognathus* (Cynodontiæ), *Tyrannosaurus* (Theropoda). The full results of this study will be published elsewhere by Adams, but meanwhile it may be worth while to record the chief general conclusions which we have reached in collaboration.

1. It seems impossible to work out the jaw musculature of *Dinichthys* either on the dipnoan or on the ordinary teleostome bases and a study of the muscle areas by Adams indicates a unique type of jaw movements, a fact of no little phylogenetic significance, in view of the disputed relationships of this group.

2. The above mentioned conclusions of Dollo and of Gregory regarding the origin of

[4] "Die Reichertsche Theorie," *Archiv. für Anat. und Entw.*, Supplement Band, 1913.

[5] *Bull. Amer. Mus. Nat. His.*, Vol. XXVII., 1910, pp. 125–143; *Jour. Morph.*, Vol. XXIV., 1913, pp. 23–35.

[6] *Proc. Zool. Soc.*, 1912, pp. 419–25.

[7] *Proc. Zool. Soc.*, 1914, pp. 779–85.

the temporal and antorbital fenestræ of reptiles are reinforced by much additional evidence.

3. The inferred conditions of the jaw musculature of *Cynognathus* are entirely in harmony with the views (*a*) that in the mammal the back part of the reptilian jaw became transformed into the accessory auditory ossicles; (*b*) that the basal portion of the mammalian alisphenoid is homologous with the reptilian pterygoid as suggested by Watson,[8] while the ascending portion seems to have been derived from the epipterygoid, as held by Broom and Watson.

4. In the transitional pro-mammals the reptilian pterygoid muscles pterygoideus anterior) became greatly reduced in correlation with the reduction of the elements behind the dentary; a possible vestige of these muscles may be the tensor tympani muscle, which runs from the basicranial region to the handle of the malleus. The mammalian internal and external pterygoid muscles are only partly homologous with those of existing reptiles and represent slips of the capiti-mandibularis mass, developed as the new joint between dentary and squamosal became established. The loss of the descending flange of the reptilian pterygoid, the secondary separation of the pterygoids along the mid-line and the transformation of the reptilian transpalatine into the true mammalian pterygoid (as held by Watson) all become more intelligible when considered in connection with the above-described changes in the musculature.

5. As a working hypothesis it is assumed that the transformation of certain elements in the temporal and occipital regions of early Tetrapoda was partly conditioned by the stresses induced upon the skull roof by the jaw and neck muscles. Comparison with lizards, *Sphenodon*, etc., clearly indicates that the prolongation of the parietal into a postero-external process joining the true squamosal was correlated with the squeezing effect of the capiti-mandibularis and depressor mandibulæ muscles. This may also be responsible for the appression and coalescence of the superior and lateral temporal elements (supratemporal and squamosal), in the early reptiles. The shifting of the post-parietals (dermo-supraoccipitals) and tabularia from the dorsal to the posterior aspect of the occiput was no doubt influenced also by the forward growth of the neck muscles upon the occiput.

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[8] *Ann. Mag. Nat. Hist.* (8), Vol. VIII., Sept., 1911, pp. 322–23.

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
SECTION D—MECHANICAL SCIENCE AND ENGINEERING

THE first session was held in the morning of Wednesday, December 30, in the engineering building, Vice-president Frederick W. Taylor and Dr. Charles S. Howe in the chair, with an attendance of about 130. It was announced that the sectional committee had recommended for election to the general committee for the office of *Vice-president*, Dr. Bion J. Arnold, of Chicago. The following officers were elected by the section:

Member of Council—Dr. Rudolph Hering, of New York City.

Member of General Committee—Morris L. Cooke, of Philadelphia.

Member of Sectional Committee—Dr. Charles S. Howe, of the Case School of Applied Science.

The program of the session was as follows:

Principles of Scientific Management: DR. FREDERICK W. TAYLOR.

Which is to Control Public Works—a Board or a Single Head?: MORRIS L. COOKE.

The Improvement and Enlargement of Transportation Facilities: GEORGE S. WEBSTER.

A Study in Cleaning Philadelphia's City Hall: WILLIAM H. BALL.

Every city, town and hamlet which owns a public building of any kind is confronted with the problem of efficient and economical cleaning. Public buildings are constantly growing in size and it is becoming more and more possible to handle the problems of their maintenance and operation on a technical basis. The fact that after what must be admitted to have been a crude study, extending over only a few months, we were able to effect economies amounting to over $30,000 a year, or $100 a day, in the cleaning of one public building, shows the possibilities. According to technical and other literature the cleaning of public buildings has been given very little